Swedish University of Agricultural Sciences
Department of Forest Ecology

Graduate Thesis in Biology 2005

Vegetation succession and biomass production after peat ash and PK-fertilization on the cutaway peatland of Näsmyran in Hälsingland, Sweden

– Vegetationssuccession och biomassautveckling efter torvaske- och PK-gödsling på utbruten torvmark på Näsmyran i Hälsingland

Stefanie Leupold

Supervisors: Tord Magnusson och Greger Hörnberg

Swedish University of Agricultural Sciences
Faculty of Forestry Sciences
Department of Forest Ecology
SE-901 83 UMEÅ

Stencilserie No. 107

ISSN 1104-1870
ISRN SLU-SEKOL-STL-107-SE

This report presents an MSc thesis in Biology, carried out at the Department of Forest Ecology, Faculty of Forest Sciences, SLU. The work has been supervised and reviewed by supervisors, and been approved by the examinator. However, the author is solely responsible for the content.

OMSLAGSFOTO: BJÖRN HÅNELL

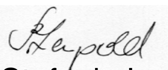
Preface

This project was carried as a 20-credit-thesis (30 ECTS) for the Department of Forest Ecology at SLU in Umeå in order to finalize my studies with a Master of Science degree in biology. The field work was carried out in May and June 2004, while the writing for the main part took place during spring 2005.

Firstly, I would like to thank both my supervisors Tord Magnusson, at the Department of Forest Ecology, SLU and Greger Hörnberg, at the Department of Forest Vegetation Ecology, SLU. I received great guidance and assistance with both the field work and writing.
Carl-Eric Lindquist at Råsjö Torv AB has been of great help and motivating all the way through this project, especially during the field work. Berndt Eriksson and Stefan Östlund, from the same company provided me with background information and further details.
I would like to thank Back Tomas Ersson and Anders Strandh for stimulating discussions on the topic of this thesis and for translating some of the Swedish literature for me.

Lastly, I would like to thank my parents, Hans-Jürgen and Renate Leupold, for supporting me the entire time of my studies.

Umeå, 5th of June 2005


Stefanie Leupold

1. Abstract

By 2010, the total area of cutaway peatlands ready for after use in Sweden is expected to be 3 000 – 5 000 ha. Afforestation of terminated peat cuttings is one of the most favoured after use options and can be suitable for commercial timber production if drainage and nutrition status are taken care of.
This study was conducted on a long-term afforestation experiment on Näsmyran in Hälsingland, Sweden. In 1991, five different tree species were planted on 40 plots with four different fertilizer treatments. The aim of this study was to assess the total biomass production and the vegetation development as a response to the fertilization. After 13 vegetation periods all plots were dominated by natural regeneration of downy birch, silver birch and pine from the surrounding forests. Still, on the fertilized plots the planted trees were thriving.

The total stem density after 13 years was 69 900 stems/hectare on the peat ash treatment (corresponding to 80 kg P and 104 kg K), 43 500 stems/ha on P40K80 (40 kg P and 80 kg K/ha), 39 300 stems/ha on P80K120, 21 200 stems/ha on P0K0, and 18 800 stems/ha on Control (no fertilizer; no planting).

The highest total biomass production, 96 tonnes per hectare (13 yrs) was recorded for the treatment P80K120, while P40K80 and ASH had a total production of 64 and 55 t/ha, respectively. The P0K0 and the Control produced only 7 and 5 t/ha, respectively. While the highest PK-fertilizer dose resulted in the highest total tree biomass production, peat ash fertilization resulted in the highest number of stems/ha.

The most productive species, in terms of single tree volume and biomass, was lodgepole pine. The areal production of Scots pine was, however, higher than for lodgepole pine on P40K80 and ASH, due to the contribution from natural regeneration for Scots pine. Comparing the two birch species, downy birch shows higher stem densities than silver birch, while the opposite is true regarding production (both single tree production and areal production).

Considering the natural regeneration, planting of Scots pine may not be necessary when the cutaway peatland is fertilized with PK-fertilizer or peat/wood ash, provided that natural seed sources are found within seeding distance (approximately 200 m). Without fertilization even after 13 vegetation periods, there was still no appropriate vegetation establishment found on the unfertilized plots. There is no doubt that establishment and development of the trees on Näsmyran are the results of fertilization.

2. Sammanfattning

Detta examensarbete genomfördes 2004 inom ett långsiktigt beskogningsförsök på en utbruten torvmark. Försöket etablerades 1991 på torvtäkten Näsmyran, Hälsingland (lat 61 46'N, long 15 40'E; 195 m ö h) där torvbrytningen delvis har slutförts. Hela det tegdikade försöksområdet omfattar 3,44 ha och är indelat i 42 parceller om vardera 20 x 40 m. 1990 plöjdes ytorna och 10 ytor gödslades med 0 kg P och 0 kg K (P0K0), 10 ytor gödslades med 40 kg P och 80 kg K (P40K80), 10 ytor gödslades med 80 kg P och 120 kg K (P80K120), och 10 ytor gödslades med torvaska motsvarande 80 kg P och 104 kg K (ASKA). 1991 planterades (förband ca 3000 plantor/ha) tall, contortatall, gran, svartgran och tamaracklärk på två ytor vardera, i respektive gödslingsbehandling. Det anlades två kontrollytor som varken gödslades eller planterades.

1995 inventerades Näsmyran för första gången med avsikten att utvärdera utvecklingen av planterade trädplantor samt etablering och utveckling av naturligt etablerad träd- och buskvegetation, fem vegetationsperioder efter avslutad torvbrytning. Tyngdpunkten låg på den naturliga etableringen samt effekter på denna av olika gödselbehandlingar. Denna tidigare studie behandlade naturlig beskogning av torvmark genom insådd från omgivande skog, för mer information se Svensson (1998). Under inventeringen 1995 anlades ytterligare en parcell (MINERAL) nordväst om försöksområdet. Avsikten med utökningen var att studera den rikliga spontana trädkolonisation som uppstått i täktområdets ytterkantefter dikesrensning, då små mängder uppgrävd mineraljord planats ut över närliggande torvytor.

I föreliggande studie inventerades trädskiktet med avseende på stamantal, höjd, diameter och trädslag. Dessutom bestämdes markvegetationen till art och täckningsgrad. Inventeringen gjordes på provytor i form av diagonala transekter utlagda i öst-västlig riktning inom varje parcell. Resultaten, inklusive beräkningar av stamvolym och total trädbiomassa ovan jord efter 13 vegetationssäsonger, presenteras som medelvärden per ha för varje behandling.
Försöksområdet var år 2004 dominerat av glasbjörk, vilken utgjorde 24 % av stammarna per hektar, räknat som medeltal för alla behandlingar. Tallen utgjorde 18 %, *Salix* spp. 15 %, vårtbjörk 11 % och gran 5 % av det totala stamantalet per hektar. De främmande trädslagen contortatall, svartgran och Tamaracklärk utgjorde, vart och ett, cirka 7 % av stamantalet på de ytor där de planterats.

Det högsta totala stamantalet per hektar återfanns på ASKA, där stamtätheten var 69 900 stammar/ha. På de P40K80-gödslade parcellerna fanns i genomsnitt 43 500 stammar/ha och på P80K120 var stamtätheten 39 300 stammar/ha. På MINERAL uppmättes 37 500 stammar/ha, på P0K0 21 200 stammar/ha och på KONTROLL 18 800 stammar/ha.

Högst trädbiomassatillväxt, 96 t per hektar, uppmättes i genomsnitt på de parcellerna med störst gödselgiva, P80K120. P40K80 gav något högre tillväxt av trädbiomassa, 64 t/ha, än MINERAL och ASKA, 57 t/ha respektive 55 t/ha. Behandlingarna utan tillförsel av gödselmedel eller mineraljord, P0K0 och KONTROLL, hade producerat endast 7 t respektive 5 t per ha.

Det mest produktiva trädslaget beträffande det enskilda trädets produktion var contortatall. Arealproduktionen av vanlig tall var dock högre än för contorta på P40K80 och ASKA, i kraft av tallens det mycket högre stamantal p g a naturlig föryngring. När man jämför de två björkarterna har glasbjörk högre stamantal än vårtbjörk men den senare uppvisar bättre tillväxt på alla behandlingar.

Under de nio år som gått efter den första inventeringen har tillståndet på de ogödslade ytorna inte väsentligen förbättras och det visar otvetydigt att gödsling (eller tillförsel av mineraljord) är nödvändig för tillfredsställande återbeskogning av utbrutna torvmarker. Resultaten av MINERAL-behandlingen visar förhållandevis höga värden för trädbiomassatillväxt, men relativt låga stamantal per ha. Detta pekar på att den naturliga föryngringen är grovt. Dock är MINERAL-behandlingens resultat statistiskt osäkra pga. den enstaka behandlingsytan.

Studien visade att ju större gödselgiva av P och K, desto högre total trädproduktion. Torvaska gav en trädproduktion som var något lägre än för tillförsel av motsvarande mängder rent PK-gödselmedel, men gav upphov till högst stamantal och var således den gynnsammaste behandlingen för naturlig föryngring.

Table of contents

3. Introduction

Sweden has a rather long tradition of forestry on peatlands. About ten million ha, or almost one-quarter of Sweden's total land surface area, is covered by peatlands of varying thickness (Larsson, 2001). Almost half of this peatland area is defined as productive forestland, having a forest productivity exceeding 1 m^3 of solid stem volume (m^3sk) per ha and year. Most of that is natural forested peatlands, but 1-1.5 million hectares has formed after drainage for timber production.

In Sweden, peat has been excavated as a fuel supplement as early as the first century, AD. Traditionally, peat was excavated manually on a small scale. However, during the last decades, the harvesting processes have been mechanized and large scale industrial peat extraction started in the 1980's. In the year 2000, about 10 000 ha were under peat extraction (Larsson, 2001). By 2003, this area had increased to 15 000 ha (Hånell, 2004). How long peat harvesting can last is limited by the thickness of the peat layer. On average, it lasts between 20 to 25 years (Larsson, 2001). Currently, about 500 ha of terminated peat cuttings are ready for restoration (Hånell, 2004). This area is expected to increase to 3 000-5 000 ha within the next five years (Hånell, 2004).

According to regulations, the peat producing companies are legally obligated to reclaim or restore the area after peat harvesting ceases. The landowner (a private owner, a municipality or the peat producer) decides which after use option is to be applied. There are a variety of alternatives, e.g. afforestation, energy forests, agricultural production, wetland restoration, and artificial lakes. From an economical point of view, afforestation seems to be favourable and is often the chosen option. Forests on cutaway peatlands can generate more than satisfactory amounts of timber or tree biomass depending on the fertility of the site, peat depth and peat type, drainage intensity, tree species and tree age (Paavilainen and Päivänen, 1995). Cutaway peatlands are regarded to be suitable for commercial timber production if drainage and nutrition status are taken care of (Aro, 2000). The nutrient composition in peat depends on the vegetation that formed it and on the degree of peat decomposition (Hånell, 2004). Peat contains considerable amounts of nitrogen (N), but mainly in a plant unavailable form, while the amounts of potassium (K) and phosphorous (P) are low. Moreover, there usually is an imbalance between nitrogen and phosphorous. The N/P-ratio in the peat tends to be about 100/2-4, while trees demand a ratio of 100/10-13 (Hånell *et al.*, 1996; Aro, 2000). P and K are usually the most important growth-limiting abiotic factors (Hytönen, 2003). These imbalances and deficiencies can be improved by soil preparations and fertilization with either PK-fertilizers (Aro, 2000) or peat or wood ash (Nilsson, 1994; Hytönen & Kaunisto, 1999; Aro, 2000; Hytönen, 2003; Näsi *et al.*, 2004). The main point is that peat as a material is notoriously low in P and K (in relation to plant need), and the nutrient availability could be improved with ash applications.

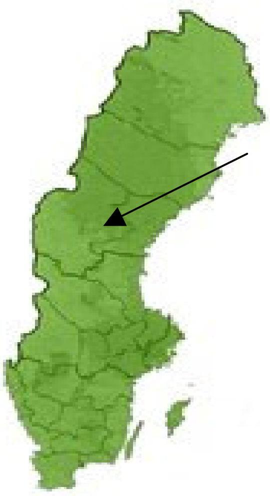
In Sweden, ash as a by-product of energy production, is produced at a rate of 1 000 000 t/yr (1/3 originates from biofuels) (Hånell, 2004). Ash has good fertilizing characteristics, because it supplies the plants with mineral nutrients (except N) and acts as a liming agent (Näsi *et al.*, 2004). While PK-fertilizers are regarded to compliment the soil with nutrients limiting tree growth, wood and peat ash also raise the soil pH and thus enhance microbial activity and nitrogen mineralization (Hytönen

& Kaunisto, 1999). Artificial fertilizers have shorter lasting growth effects (about 15 years) and refertilization may be required, especially on deeper peat layers where the trees are not able to penetrate into the underlying mineral soil (Aro & Kaunisto, 2003). Nilsson *et al.* (1994) state even shorter response periods (4-8 years) of PK-feritlizers. In other studies (Hytönen & Kaunisto, 1999), ash fertilization has shown longer lasting effects (30-40 years) in other studies.

As there have been many trials and much research carried out on peatland forestry in many countries, there is broad and deep knowledge available for use in Sweden when afforesting cutaway peatlands.

3.1. Study site

The study site, Näsmyran, is located at 61º46' N latitude and 15º40' E longitude, 195 m above sea level, in the municipality of Ljusdal, in the county of Hälsingland (Fig. 1).



The mire is situated in a lowland surrounded by ridges in the south and west. In the south-west lies the lake Finnsjö from where most of the mire's water supply originates.
The study area is on three sides surrounded by forests and on one side by continuing peat production. The peat harvesting will continue until 2007. After that the remainder of the peat production site will be available for after use.

Figure 1: Map of Sweden, arrow indicating the location of the study site Näsmyran.

In 1991, a fertilization and tree species experiment was established on a part of Näsmyran where peat cutting was finished. The experimental area (3.44 ha) had a remaining peat layer of almost one meter (in no subarea less than 0.5 m). The distance between the open drainage ditches was 20 m and the treatment plots were 40m x 20m. In this long-term experiment, five tree species i.e. Scots pine (*Pinus sylvestris* L.), lodgepole pine (*Pinus contorta* Dougl.), Norway spruce (*Picea abies* (L.) Karst.), black spruce (*Picea mariana* Britton, Sterns & Poggenb.) and tamarack (*Larix laricina (Du Roi)* K.Koch) were planted on four different soil treatments. Twenty plots were planted and fertilized with different amounts of phosphorous and potassium (Figure 2); i.e. ten plots with 40 kg/ha phosphorous and 80 kg/ha potassium (P40K80), ten plots with 80 kg/ha phosphorous and 120 kg/ha potassium (P80K120). Ten plots were fertilized with peat ash (ASKA, corresponds to 80 kg/ha phosphorous and 104 kg/ha potassium) and ten plots were not fertilized (P0K0).

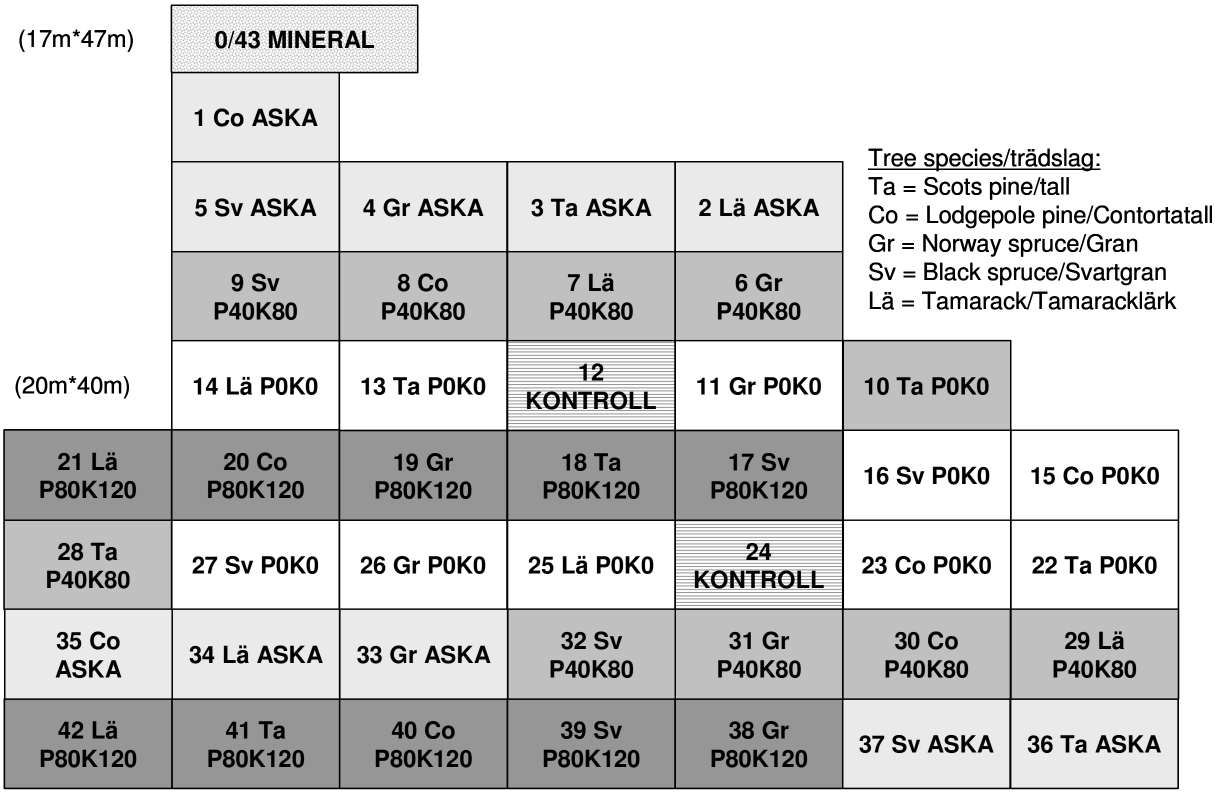


Figure 2: Afforestation experiment on Näsmyran/Beskogningsförsök på Näsmyran (Svensson, 1998)

All plots were planted with about 3 000 plants/ha of the five tree species mentioned earlier (the exact planting density is not known, but is most probably within the interval 2 500-3 000 seedlings/ha). This resulted in four times ten different soil treatments with two replications for each tree species and each soil treatment. Two plots were neither fertilized nor planted (KONTROLL) and serve as control areas to assess the establishment of natural tree regeneration and colonization. Outside (NW of) the original experimental area, one extra treatment plot was established in connection with the 1995 inventory. This was because very strong effects on colonization were observed in an area where excavated material from a deep drainage ditch, reaching down to sandy/silty mineral soil, was levelled out over adjacent peat surfaces. Consequently, mineral particles were mixed into the surface layer of the residual peat layer. That area was included in the experiment to represent a ”surface application of mineral soil” treatment. This treatment has only one plot and differs slightly in shape (17m x 47m).

In 1995, a first inventory was carried out by Svensson *et al.* (1998): to assess the colonization and development on the individual and species-level; to describe the spatial and three dimensional-structure; to assess the survival rate of the trees planted on the various soil treatments; and to survey the colonization of ground vegetation. The naturally regenerated species found were Scots pine, silver birch (*Betula pendula* Roth.), downy birch (*Betula pubescens* Ehrh.), willows (*Salix spp.*), alder (*Alnus incana* (L.) Moench) and rowan (*Sorbus aucuparia* L.).

Svensson *et al* found that the treatments formed three distinct groups, with respect to tree colonization: 1) MINERAL (37 500 stems/ha); 2) P80K120 (26 450 stems/ha),

P40K80 (22 000 stems/ha) and ASKA (23 200 stems/ha); and 3) P0K0 (3400 stems/ha) and KONTROLL (3 000 stems/ha).
Four species made up 98 % of all natural regeneration. Scots pine dominated the colonization with 49 %, downy birch totalled 19 %, willows 15 %, and silver birch 15 %, respectively. In total, natural regeneration accounted for 87 % of all individuals. The average densities of planted trees per soil treatment were 2 800 stems/ha on P80K120, 3 000 on ASKA, 2 750 stems/ha on P40K80, and 2 050 stems/ha on P0K0. P80K120 showed the highest stem density in the layer of trees > 1,3 m.

Survival of planted trees and natural regeneration was closely related to nutrient application. Moreover, the colonization occurred along a clear dispersion gradient so species composition and quantity of colonization depended on the distance to the closest natural seed source.

4. Objectives

The study at hand aimed at assessing figures for biomass production as response to different doses of PK-fertilizers and peat ash on cutaway peatland. The objectives were to:

- Assess tree species composition
- Calculate the biomass production on the various soil treatments for planted and naturally regenerated tree species
- Evaluate survival and development of planted tree species; is planting necessary?
- Study if spontaneous natural tree colonization improved over time on the non-fertilized spots
- Sampel ground cover vegetation and classify it to site types according to Hånell (1991) and correlate those to the soil treatments

5. Material and methods

In 2004, the long-term experiment was inventoried a second time. Similar to the inventory in 1995 (Svensson *et al.,* 1998), diagonal transects of 24m^2 (40m x 0.6m) were laid out in a west-east direction on all plots. Because there was only one plot with the MINERAL-treatment, two transects of the same size as the other ones were laid out there, one along the west to east and the other along the south to north diagonal.

Along every meter of each transect, all trees above 0.1 m were counted and identified. All trees with the centre of the stem inside the transect were counted. Heights and diameters at breast height (DBH) were measured for all stems taller than 1,3 m. The DBH was measured with a calliper, while the height was measured with the help of a 5 m rod and a SUUNTO clinometer.

From the tree data collected, the number of stems per transect, stem volume and total tree biomass above the stump (stem over bark, living branches, dead branches and needles (only conifers)) for each tree was calculated and summarized according to Näslund's minor volume function (Håkansson, 1994) and Marklund's biomass functions (Marklund, 1988). Thereafter number of stems and volume per hectare were determined and averaged for each soil treatment. After 13 vegetation periods, it was not possible to distinguish between the planted and naturally regenerated individuals. Thus, there are two averages per hectare calculated for Scots pine and Norway spruce; one gives the average of the two transects per soil treatment where Scots pine and Norway spruce were planted but also naturally regenerated; the other represents the average of the eight transects per soil treatment where the two species had only regenerated naturally.

The plants occurring on a vertical sight line along the transect laid out were included. The data was collected for each particular plant species according to the following categories: 1= single specimens, 5= 5 % coverage, 10 = 10%, 20 = 20%,…100 =100%. Bare peat and litter were surveyed and labelled according to the same classification. The collected data was summarized and averaged, in order to compare the different soil treatments. From the species composition in the field layer and their cover, the different treatments were classified according to Hånell (1991).

6. <u>Results</u>

During the inventory nine tree species and two genus were recorded. The planted tree species found were Scots pine, Norway spruce, black spruce, tamarack, lodgepole pine; plus the naturally regenerated species silver birch, downy birch, birch spp. (probably hybrids), willow spp., grey alder, and rowan.

6.1. Total (> 0,1 m) tree species composition

The most abundant tree species, calculated as the average among all treatments, was downy birch. It made up 28 % of the stems, while Scots pine made up 21%, willow spp. 18%, silver birch 14%, Betula spp. 8% and Norway spruce 6%. For this average, the numbers for Scots pine and Norway spruce were generated from an average of both planted and naturally regenerated trees on all soil treatments. The other planted species, being tamarack, black spruce and lodgepole pine, each make up approximately 1% of the stems, as an average including only plots were they were planted. The remainder of 2 % was other tree species as mentioned earlier.

Figure 3 below shows the average species composition in percent for each soil treatment.

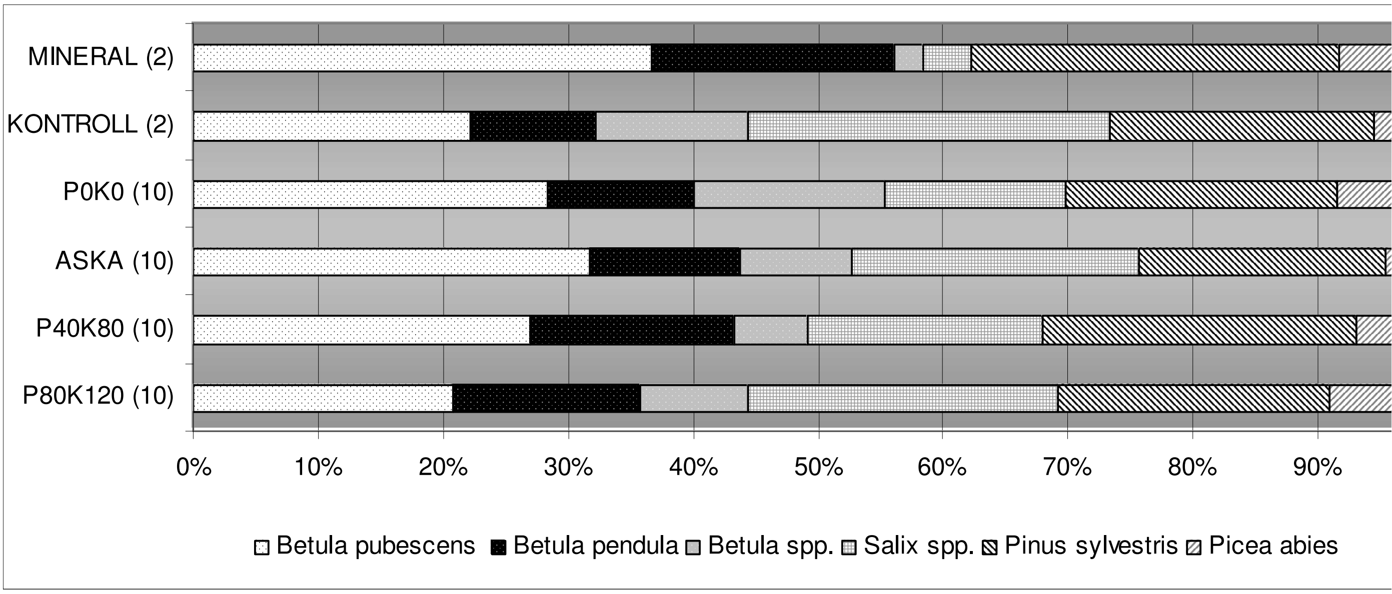


Figure 3: Average species composition of each soil treatment (the numbers in brackets represent the number of transects within each soil treatment).

6.2. Number of trees

6.2.1. All trees (>0,1 m)

The highest total number of stems/ha on average per soil treatment, regardless of tree species composition or origin of plants, was found on ASKA (69 900 stems/ha) and on P40K80 (43 500 stems/ha) as shown in Fig. 4. The corresponding numbers for P80K120 were 39 300 stems/ha; MINERAL, 37 500 stems/ha; P0K0, 21 200 stems/ha; and lastly KONTROLL, 18 800 stems/ha. This calculates to an average of 38 300 stems/ha for all tree species and all soil treatments.

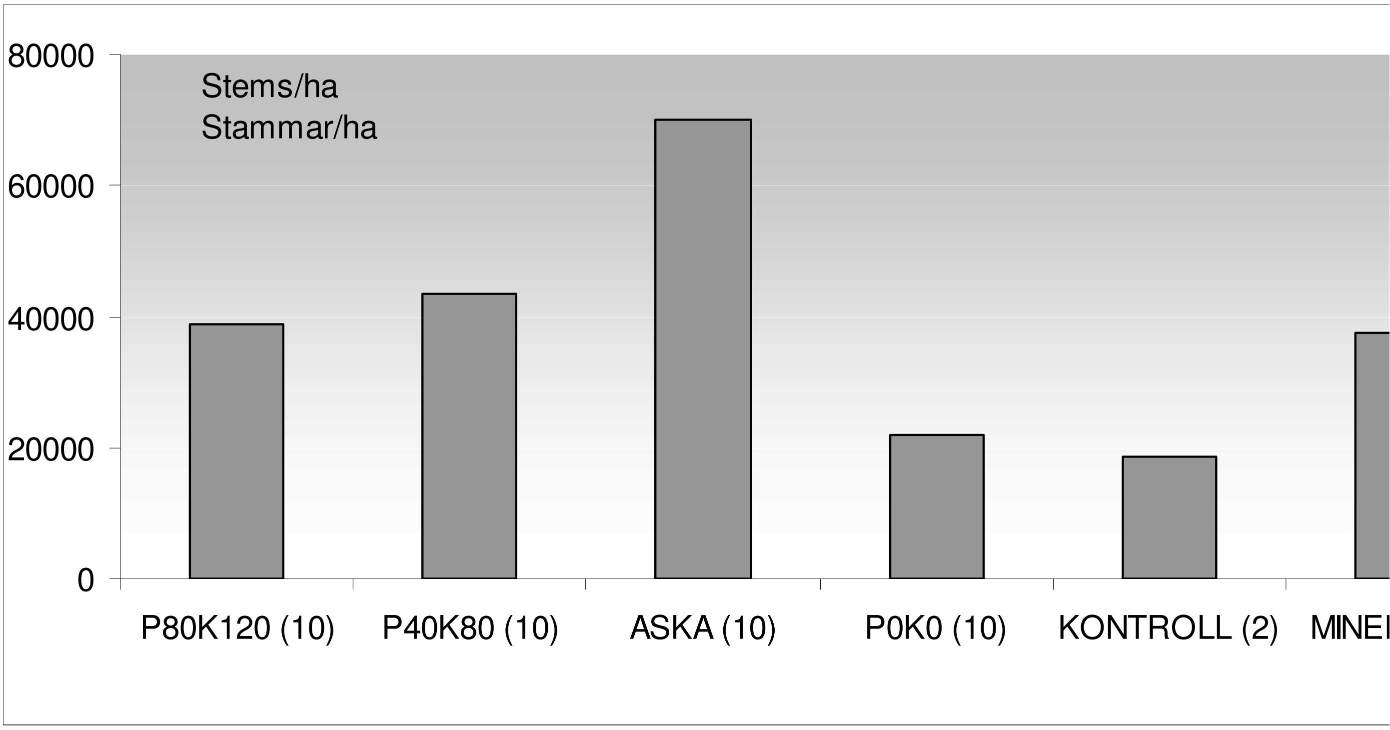


Figure 4: Average total number of stems/ha for all tree species (numbers in brackets represent the number of transects).

6.2.2 Total no. of trees (> 0,1 m) grouped by tree species

The highest average number of stems/ha for each separate tree species on ASKA was downy birch (20 900 stems/ha) and willow *spp*. (15 100 stems/ha), and on MINERAL it was downy birch with 13 800 stems/ha on (Fig. 5). On P80K120, willow *spp.* and planted (P) and naturally regenerated (NR) Scots pine were most abundant (9 000 and 8 950 stems/ha, respectively). For P40K80 the highest average of stems were found for P+NR-Scots pine and downy birch (13 350 and 11 400 stems/ha, respectively). On P0K0, the majority of stems was downy birch and P+NR-Scots pine (5 250 and 4 170 stems/ha, respectively), while the species composition on KONTROLL was mostly dominated by willow spp. (5 420 stems/ha) and downy birch (4 170 stems/ha). More information and numbers for the other tree species can be found in Table 2 to 7 in the Appendix.

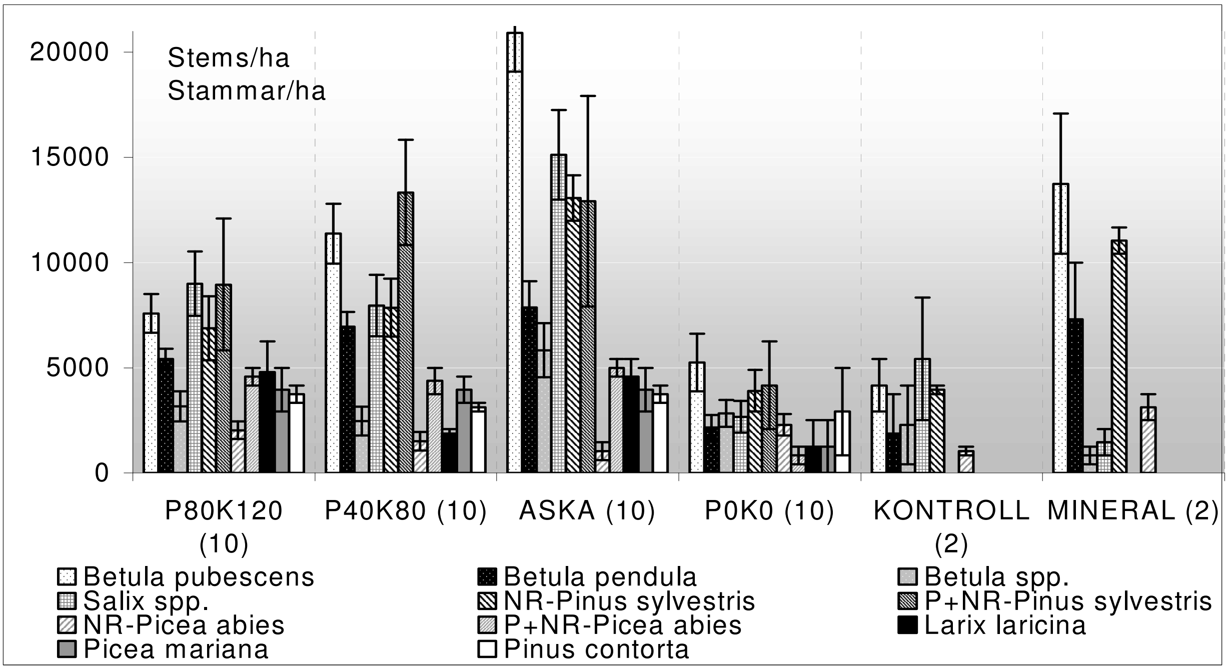


Figure 5: Average total number of stems (> 0,1 m) for each tree species and standard error of the mean (the number in brackets represents the number of transects). Scots pine and Norway spruce were calculated both as an average of only naturally regenerated (NR) trees (8 transects) and also as planted plus naturally regenerated (P+NR) trees (2 transects).

6.2.3 Trees > 1,3m

In the tree layer above 1,3 m (DBH), the average number of stems/ha were 24 700, 24 650, 20 900 and 3 250 stems/ha, for P80K120, ASKA, P40K80 and P0K0, respectively (Fig. 6).

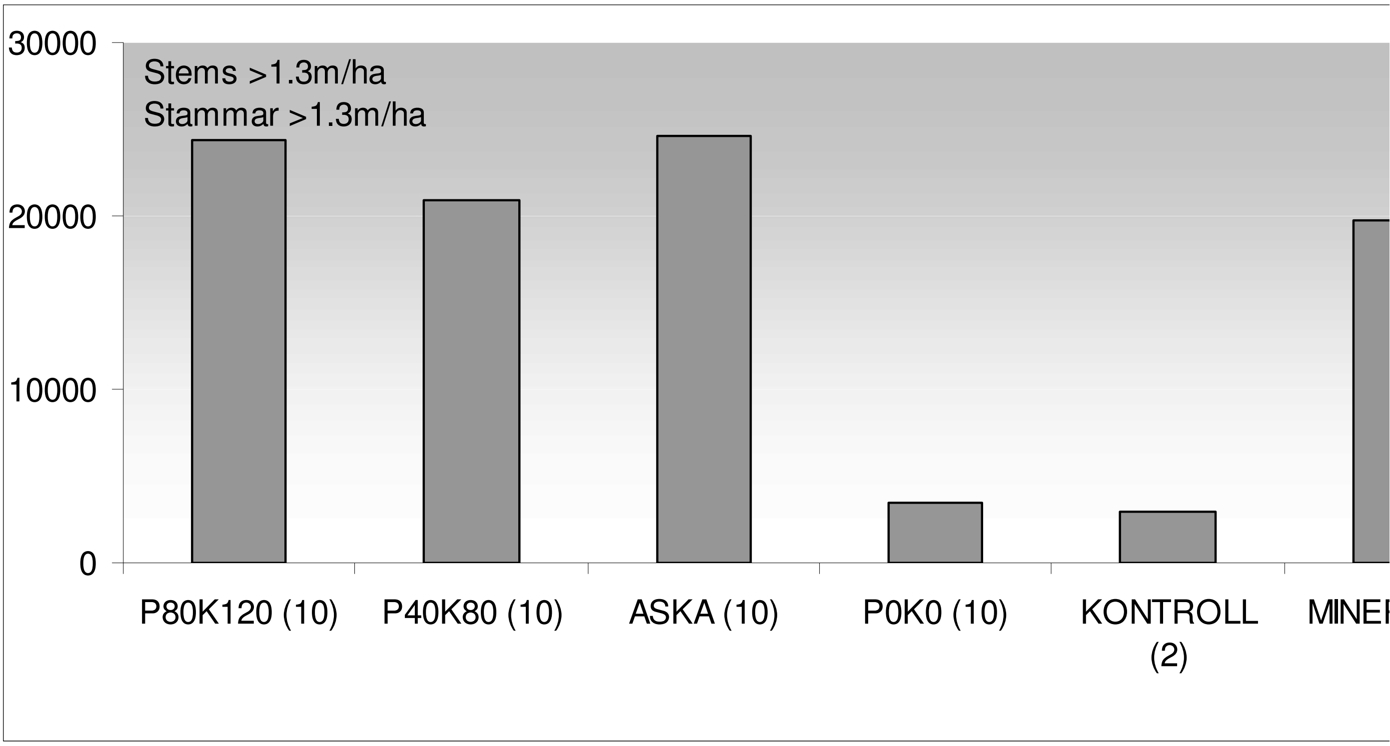


Figure 6: Average number of stems > 1,3m/ha all tree species (numbers in brackets represent the number of transects).

6.2.4 Trees > 1,3 m grouped by tree species

The highest number of trees > 1,3 m for each separate tree species was P+NR-Scots pine (10 200 stems/ha on both ASKA and P40K80), and downy birch (8 500 stems/ha on MINERAL) (Fig. 7). On P80K120, the most abundant tree species were P+NR-Scots pine (7 900 stems/ha) and willow spp. (4 950 stems/ha). The corresponding number for P0K0 were 1 500 stems/ha of lodgepole pine, 1 250 stems/ha of tamarack and 1 250 stems/ha of downy birch.

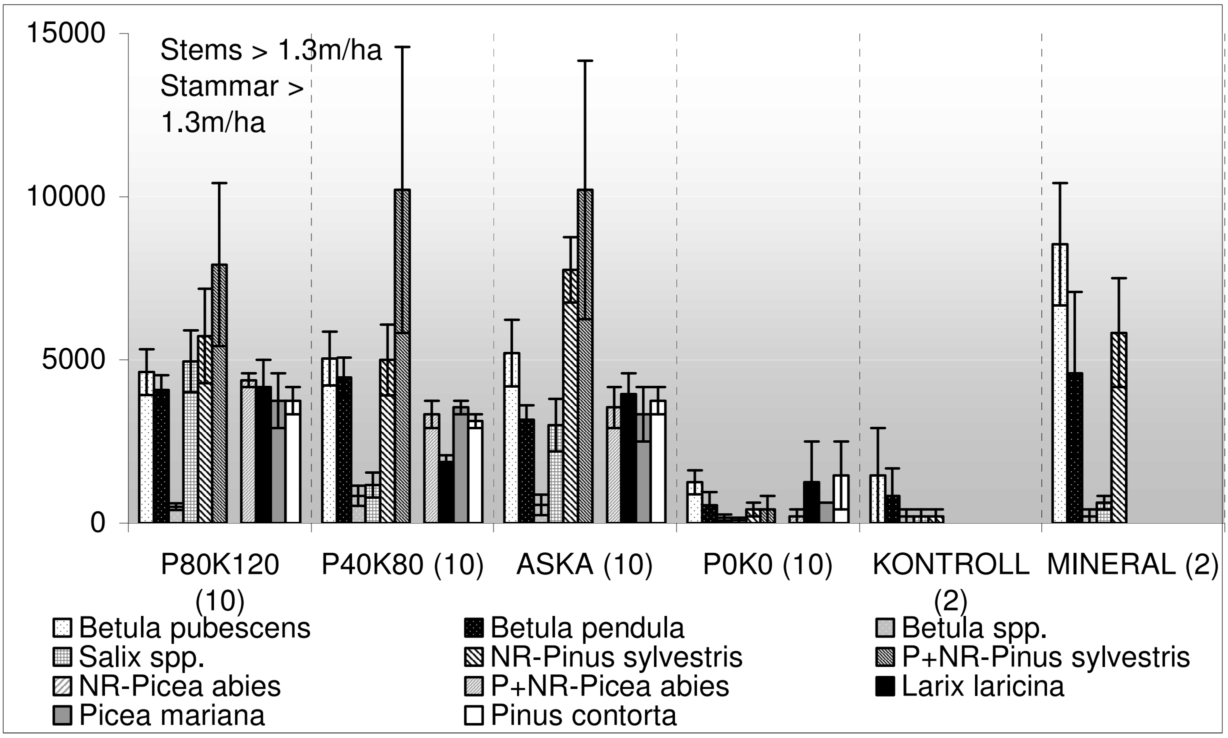


Figure 7: Average number of stems > 1,3m for each tree species and standard error of the mean (the number in brackets represents the number of transects). Scots pine and Norway spruce were calculated both as an average of only naturally regenerated (NR) trees (8 transects) and also as planted plus naturally regenerated (P+NR) trees (2 transects).

6.2.5 Planted trees

Survival of planted trees can be estimated for those species that have no surrounding seed sources, i.e. black spruce, lodgepole pine and tamarack larch. Some seed regeneration from the planted trees themselves may have occurred, but should be negligible in the >1,3 m height group. The original planting density is assumed to have been between 2500 and 3 000 seedling/ha. The lowest survival of any planted species was found on P0K0. Scots pine naturally regenerated to high numbers, especially on ASKA and P40K80 (Fig. 5 and 7). In contrast, Norway spruce naturally regenerated to a lower degree (NR < P+NR) even though the potential for plentiful natural regeneration was present. On P0K0, Norway spruce declined to an average of 833 stems/ha. Tamarack showed lowest survival on P40K80, here the average number of stems decreased to 1 875 stems/ha. Tamarack also decreased to 1 250 stems/ha on P0K0 where also black spruce showed lowest survival (1 250 stems/ha). Lodgepole pine on average showed good survival on all soil treatments (compare also Table 2 to7 in the Appendix).

6.3 Volume

The highest average total stem volume, 74 m^3/ha, which corresponds to a mean annual growth index (MAI) of 5,7 m^3/ha/yr,was generated on P80K120 plots (Fig. 8). The average stem volume for P40K80 was 48 m^3/ha (MAI 3,7 m^3/ha/yr), for MINERAL 42 m^3/ha (MAI 3,3 m^3/ha/yr), for ASKA 39 m^3/ha (MAI 3,0 m^3/ha/yr), for P0K0 4,3 m^3/ha (MAI 0,3 m^3/ha/yr) and for KONTROLL 3,6 m^3/ha (MAI 0,3 m^3/ha/yr).

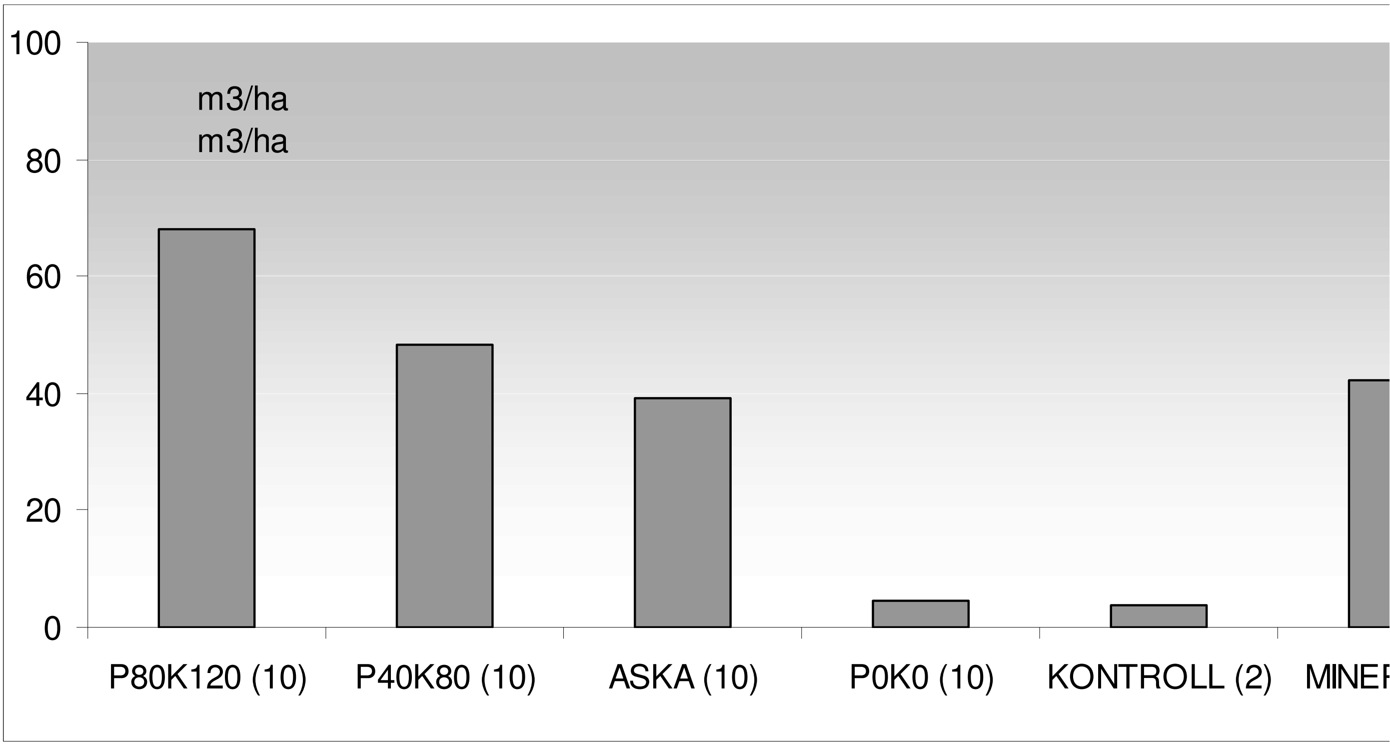


Figure 8: Average stem volume [m^3/ha] of all tree species, separated by form of establishment (numbers in brackets represent the number of transects).

6.4 Volume grouped by tree species

On P80K120 plots, the highest stem volume, 57 m^3/ha, was found for lodgepole pine. P+NR-Scots pine produced on average 42 m^3/ha and P+NR-Norway spruce 20 m^3/ha (Fig. 9). The results on P40K80 for P+NR-Scots pine and lodgepole pine were 38 and 27m^3/ha, respectively. On ASKA plots, lodgepole pine was the most productive species (30 m^3/ha), followed by P+NR-Scots pine (27 m^3/ha). On MINERAL, the highest stem volume producer was silver birch (22 m^3/ha), followed by downy birch (11 m^3/ha) and NR-Scots pine (9 m^3sk/ha).

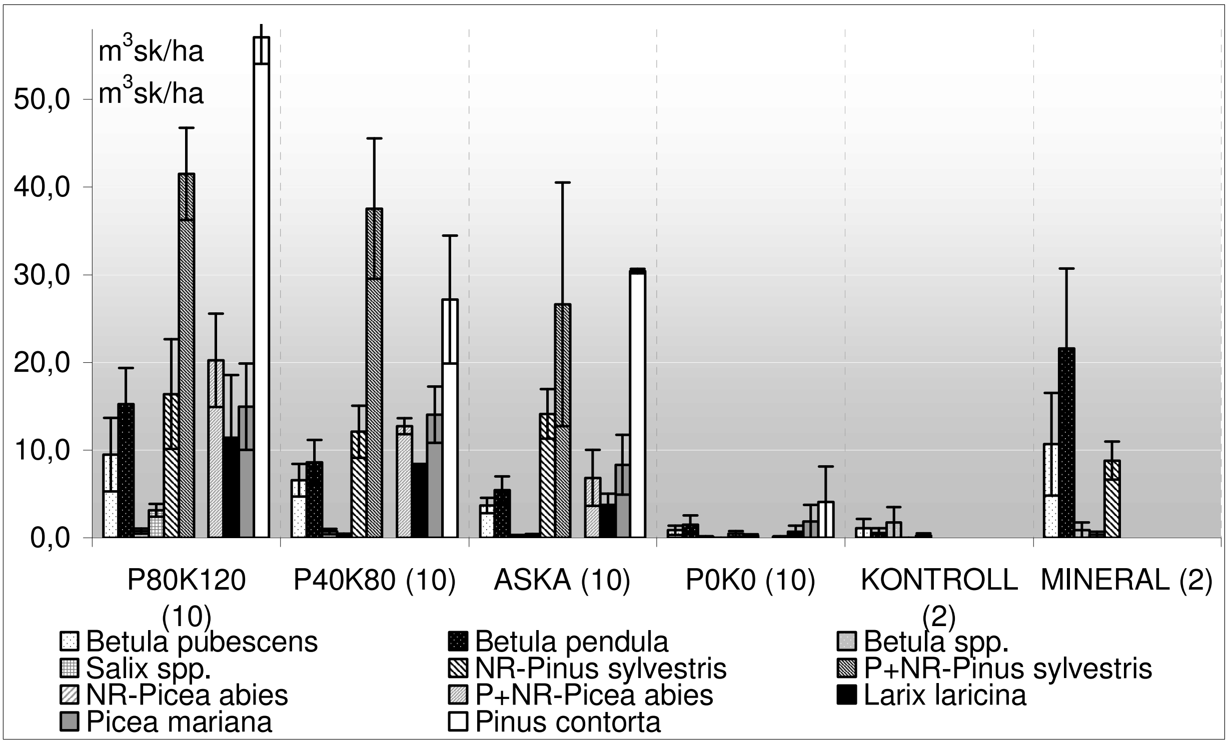


Figure 9: Average stem volume [m^3/ha] for each tree species and standard error of the mean (the number in brackets represents the number of transects). Scots pine and Norway spruce were calculated both as an average of only naturally regenerated (NR) trees (8 transects) and also as planted plus naturally regenerated (P+NR) trees (2 transects).

6.5 Biomass production

The average total biomass production for all tree species and soil treatments was 47 t/ha (Fig. 10). Depending on soil treatment, the average total biomass amounts can be ranked as follows: P80K120, 96 t/ha; P40K80, 64 t/ha; MINERAL, 57 t/ha; ASKA, 55 t/ha; P0K0, 7 t/ha and KONTROLL, 5 t/ha.

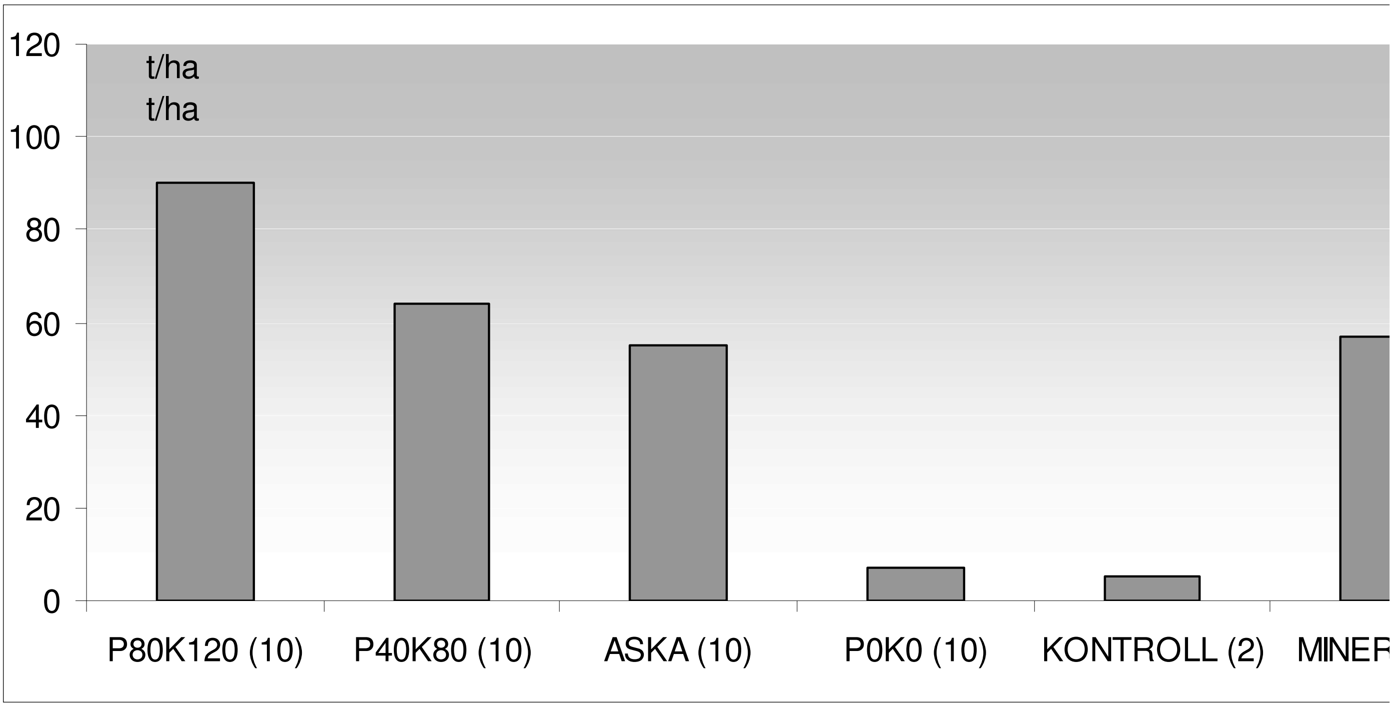


Figure 10: Average total biomass [t/ha] of all tree species, separated by form of establishment (numbers in brackets represent the number of transects).

6.6 Biomass production by tree species

The highest amounts of total biomass for each tree species was 62 t/ha of lodgepole pine and 50 t/ha of P+NR-Scots pine on P80K120 (Fig. 11). On P40K80, P+NR-Scots pine and lodgepole pine on average totalled 48 t/ha and 31 t/ha, respectively. Also on ASKA, P+NR-Scots pine and lodgepole pine produced the highest averages (36 and 35 t/ha, respectively). In contrast, lodgepole pine totalled 6 t/ha, black spruce 3 t/ha and silver birch 3 t/ha on P0K0. On MINERAL, silver birch totalled 28 t/ha and downy birch 14 t/ha.

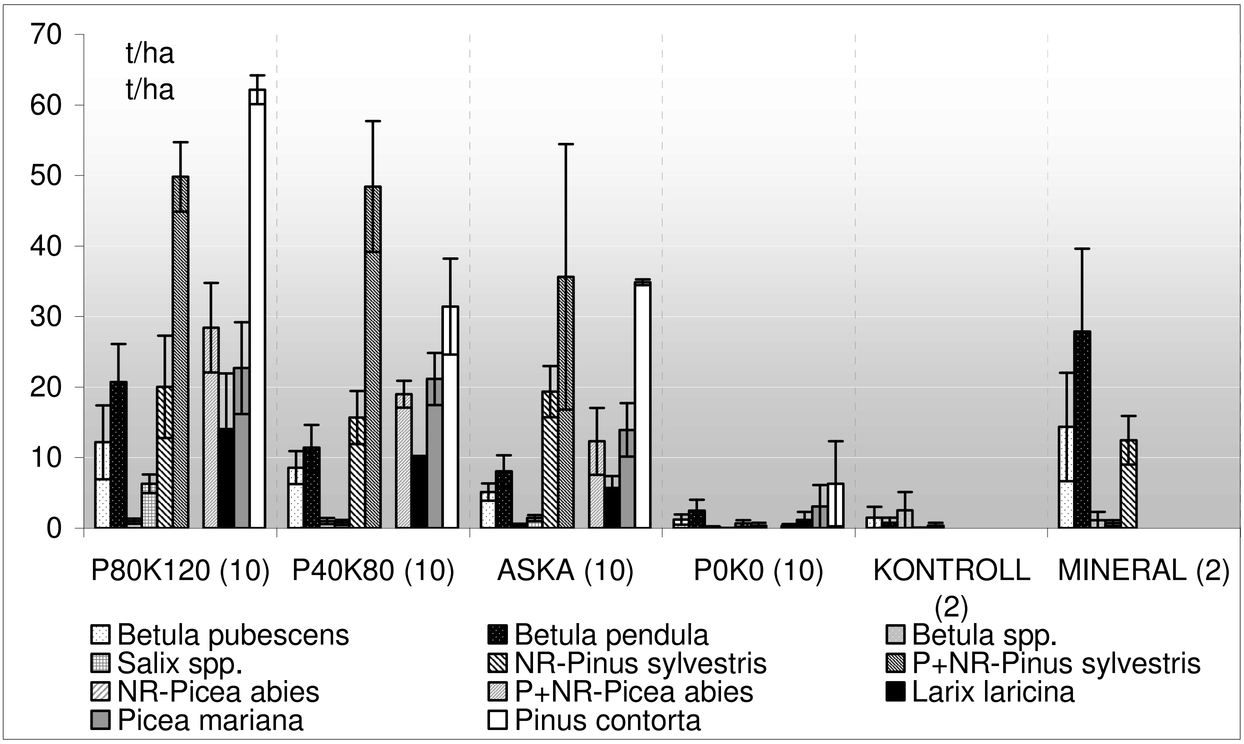


Figure 11: Average total biomass [t/ha] for each tree species and standard error of the mean (the number in brackets represents the number of transects). Scots pine and Norway spruce were calculated both as an average of only naturally regenerated (NR) trees (8 transects) and also as planted plus naturally regenerated (P+NR) trees (2 transects).

6.7 Ground vegetation

Sixty-four field and bottom layer species such as dwarf shrubs, herbs and mosses etc. were recorded (see table 8 in the appendix). Fig. 12 shows the average ground cover of vegetation, litter or bare peat, respectively, for the different soil treatments. P0K0 and KONTROLL were mostly free of vegetation. The highest vegetation cover was found on ASKA and P40K80. Litter dominated the ground on MINERAL and P80K120.

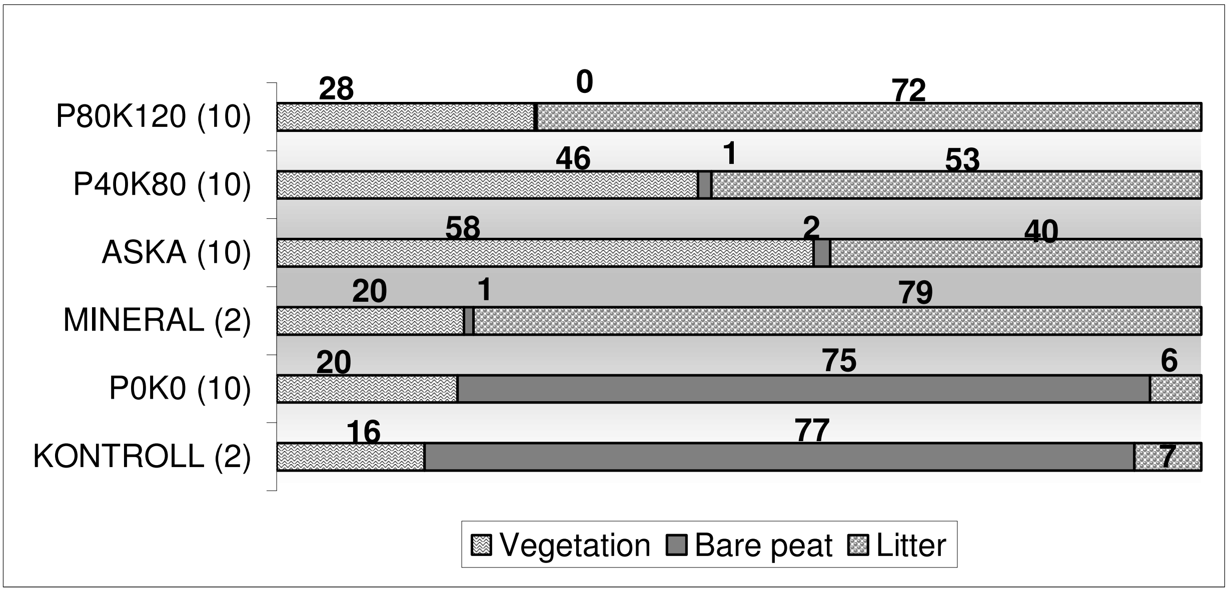


Figure 12: Average ground cover percentages of vegetation, bare peat and litter on the different soil treatments.

Table 1 below shows the classification of the different soil treatments according to Hånell (1991). There were no tall herb types found. Most of the treatments could be classified as low herb type and marsh andromeda-cranberry type.

Table 1: Number of transects classified according to Hånell (1991)

Soil treatment	Tall herb type	Low herb type	Bilberry-horsetail type	Tall sedge type	Dwarfs shrub type	Carex globularis type	Low sedge type	Marsh andromeda-cranberry type	Number of transects
P80K120		5		1			1	3	10
P40K80		3		2				5	10
ASKA		3						7	10
P0K0		4					2	4	10
KONTR.		1						1	2
MINERAL					1			1	2
TOTAL		16		3	1		3	21	44

7. Discussion

7.1. Tree species composition and succession development

During the eight vegetation periods after the first inventory, the total (> 0,1 m) tree species composition over the whole experimental area has changed from Scots pine-dominated to downy birch-dominated. A similar birch dominance compared with Scots pine can be discerned from Fig. 3. The decrease in total stem density of Scots pine from 1995 to 2004 could have resulted from competition for light from other species, mainly birch. Scots pine is a weaker competitor in that case and is, when suppressed, not as shade-tolerant in the long run (Engelmark & Hytteborn, 1999). Another reason could be that Scots pine seeds are bigger and heavier than birch seeds, thus they are more difficult to disperse into dense stands from the surrounding seed sources. This can be considered true if it is assumed that there is no natural regeneration from the Scots pines inside the experimental area. When the experiment was started, the plots were completely vegetation-free and seeds from Scots pine, birch and other tree species could disperse onto the bare peat without hinder. In 1995, almost all plots have been dominated by Scots pine (compare p. 17 in Svensson *et al.*, 1998). Scots pine totalled 49 % of all individuals found during the 1995- inventory. In 2004, Scots pine has decreased to 21 % of all stems/ha, while downy birch shows an increase from 19 % in 1995 to 28 % in 2004. Nevertheless, looking at Fig. 7, Scots pine dominates among trees taller than 1,3 m on all fertilized soil treatments. This dominance is presumably the result of a rapid and successful initial colonization by the Scots pine, and to some extent strengthened by the planting of pine on 20 % of the plots. On all fertilized treatments and on P0K0, the number of stems/ha (both > 0,1 m and > 1,3 m) of planted and regenerated Scots pine (P+NR) was higher than the average of purely naturally regenerated Scots pine. However, natural regeneration of Scots pine resulted in sufficient number of stems/ha for the establishment of production forests.

In general, birch species, especially downy birch, were found to be dominating in numbers of plants/ha (> 0,1 m) (Fig. 5 and 7). Similarly, the upper canopy layer was dominated by downy birch on most of the treatments. Birch is a tree with a multilayered branchsystem (Schnitzler & Closset, 2003). The thin and small foliage lets a lot of light penetrate, even at high stem densities. Thus there seems to be enough light coming through the birch dominated canopy for germination, survival and appropriate growth of silver birch, Scots pine and other tree species. Further, downy birch is said to show good growth in younger development stages (Schnitzler & Closset, 2003). Thus, the birch-dominance in the lower tree layers can be explained even though birch is classified as shade-intolerant (Engelmark & Hytteborn, 1999; Pöllänen *et al.*, 2004). Downy birch was found at extremely high densities on ASKA (Fig. 5). In a Finnish afforestation study on PK- and ash fertilized cutaway peatlands where downy birch had been sown (Tillman-Sutela, 2004), it was found in densities to up to 301 400 plants/ha on ash-fertilized plots. Even after some years, the numbers were still high while on unfertilized plots the numbers had decreased significantly (ibid.). Consequently, ash fertilization results in very good conditions for establishment and prevalence of that species.

Regarding willow spp., Fig. 5 gives higher numbers of stems/ha of this genus than Fig. 7 does (particularly the case for P40K80 and ASKA). This can be explained by field observations where it was noted that most of the willow-trees were multi stemmed. Further, most of the willow-trees were suppressed by herbivory and are consequently less abundant in the layer of trees taller than breast height.

7.2. Volume development and biomass production

There were higher stem volumes and total biomass averages on the PK-fertilized treatments where the number of stems was lower than on ASKA. The average stem volume and total biomass production was lower on ASKA, but here the stands were most dense. In afforestation experiments in southern Värmland, wood ash resulted in high biomass production for all tested species, e.g. Scots pine, birch and grey alder but not the two willow clones (Nilsson *et al.*, 1994). There seems to be a trade-off between number of stems and volume or biomass/ha. In the case of Näsmyran, it is likely that the lower stem volumes and total biomass on ASKA were due the very high numbers of stems/ha.

A common general view is that downy birch is more abundant on moist peat soils (Engelmark & Hytteborn, 1999), and that silver birch is favoured by mineral soil (Hytönen & Kaunisto, 1999). The present investigation on drained peat shows that downy birch is somewhat more dense than silver birch. In contrast, silver birch showed much higher individual tree volume and biomass values than downy birch.

It could be speculated that the trees have penetrated into the underlying mineral soil from where nutrients can be obtained. As mentioned earlier, PK-fertilization may have shorter-term effects (than ASKA) on the nutrition supply for plants. Since root development below 20-30 cm usually is very scarce in drained peat, the high numbers for volume and biomass/ha on the PK-fertilized plots can once again be assumed to result from influence of PK-fertilization. That trees grow well (at high numbers and with satisfactory volume and biomass production) on peat soils with mixed-in mineral material, as seen on the MINERAL plot, has also been shown by Aro (2000).

Because of the earlier mentioned herbivory on willow spp., the stem volume and total biomass figures (Fig. 9 and 11) are comparatively low for this species. This can most clearly be seen on P40K80 and ASKA. The corresponding numbers are not as low on P80K120, where the influence of the higher fertilizer dose probably has resulted in quicker growth.

7.3. Survival and development of the planted trees

Natural regeneration dominates all soil treatments and all size classes. As could have been expected, there was no clear evidence found that black spruce or tamarack has naturally regenerated. Lodgepole pine should have had potential for natural regeneration, but it was not possible to identify any seedlings of that species with certainty. Generally, the planted species showed good survival on the fertilized plots but not on P0K0.

The average number of stems/ha of the planted species were very high (table 2-5 in the appendix and Fig. 5 and 7); i.e. higher than the 3 000 stems/ha that were planted. As mentioned earlier, higher numbers than 3 000 stems/ha for Scots pine and Norway spruce originated from the natural regeneration of these species on the plots where they were planted. If one considers that the inventory was carried out correctly and that all calculations are precise, the averages of black spruce, tamarack and lodgepole pine should not total more than 3 000 plants/ha. Keeping in mind that planting on Näsmyran was carried out by contractors there is a possibility that there were more than 3 000 trees planted per hectare. However, there is also a possibility for a systematic error made when counting the trees. During the inventory, it was observed that particularly black spruce had more than one stem per planting spot. In those cases, there was at least one stem growing taller than 1,3 m and the other joint stems were not as tall. Perhaps the seedlings were planted as a bundle. Otherwise, there could have occurred vegetative regeneration. However, disregarding Scots pine, the average total number of stems/ha (Fig. 5) found at present show satisfactory survival of the planted species. Also, competition from other trees has not reduced their numbers on the fertilized plots.

Lodgepole pine showed the highest volume and biomass production on all soil treatments where the species was planted (Fig. 9 and 11). Lodgepole pine can produce up to 34-40 % more biomass compared to Scots pine given that an appropriate provenience was chosen (Segebaden, 1993). Additionally, it shows higher vitality and better survival than Scots pine (ibid.). However, the afforestation with lodgepole pine should be handled with care thinking of hybridization with Scots pine and related nature conservation problems. The volume and biomass production of black spruce and tamarack were not as high as that of lodgepole pine.

7.4. Improvement of spontaneous colonization on non-fertilized plots

It becomes obvious that even after 13 vegetation periods there was not much improvement on the colonization of the unfertilized bare peat (Fig. 12). Natural colonization of mosses, herbs and trees is slow as peat decomposition is low and the amount of available nutrients restricted. Vegetation covers the bare peat still only in patches. The patchy colonization by mainly birch on KONTROLL could be due to mineral soil contamination from drainage ditches during the maintenance work carried out when the experiment was started, or that fertilizer could have been spilled from the tractor by mistake when crossing over the control plots.

7.5. Ground vegetation development

MINERAL, P80K120, P40K80 and ASKA showed similar percentages of ground cover (Fig. 12). Most of the ground was covered by litter while the remainder was covered by vegetation. Lack of light under the higher stem densities on the afore-mentioned soil treatments resulted in a higher percentage of litter and vegetation cover, but very little percentage of bare peat. Contrarily, on P0K0 and KONTROLL, most ground was vegetation-free (bare peat). This leads to the assumption that there are similar nutrient conditions in the soils of the aforementioned groups of soil treatments.

Decomposition and mineralization returns nutrients to the soil. Birch litter is found to be higher in nutrients (Schnitzler & Closset, 2003) compared with the other tree species found on site. Since birch is most abundant on all soil treatments, an increase in nutrient content can be expected in the top layer of the soil. That in turn favours a more diverse species composition and higher abundance of species. However, this is only true to some extent, since under very dense tree canopies the ground vegetation cover decreases due to light limitations. Ash application with its subsequent pH-increase seems to favour greater diversity and species abundance in the ground vegetation. This can be seen on ASKA (Fig. 12).

The Hånell (1991) classification divides 8 site types according to their forest productivity potential as follows (from highest to lowest):tall herb type, low herb type, bilberry-horsetail type, tall sedge type, dwarf shrub type, Carex globularis type, low sedge type and marsh andromeda-cranberry type. This system was developed for natural to drained semi-natural conditions. It is used in the present study to test if indicator plants invading bare peat still indicate relative nutrient conditions. Looking at table 1, most of the treatments were identified as low herb and marsh andromeda-cranberry type according to Hånell (1991). Five of the P80K120 transects were classified as low herb types, one as tall sedge type, one as low sedge type and three transects were classified as marsh andromeda-cranberry type. As could have been expected the majority of the plots with the highest fertilizer dose was identified as the higher forest productivity site types. The P40K80-treatments showed similar results. Half of the treatments were classified as low herb and tall sedge type and the other half as marsh andromeda-cranberry type. One could have expected that more of the ASKA-treatments would have been classified as site types with higher forest productivity potential, but only three transects out of ten were low herb type and seven marsh andromeda-cranberry type. Even more surprising is that four P0K0-transects out of ten were identified as having better forest productivity potential although fig. 8 and 10 prove that tree growth is very low here. The KONTROLL-transects were identified as low herb and marsh andromeda-cranberry type. This again is probably the result of spillage from the drainage ditches during maintenance work as mentioned earlier.

The site type results are difficult to interpret and lead to the presumption that using Hånell's classification is not appropriate for sites like the study area where all colonization started from zero after the peat production ceased. In the best case these site type results could hint that fertilization formed advantages for colonization of plants which has already been supported by the number of stems and volume and biomass development of the planted and naturally regenerated trees. Another important area of research, that was not investigated in this study but affects the establishment and productivity of plants, includes the biotic interactions between below and above ground communities (see for example Wardle *et al.* 2004).

8. Conclusions

Since the first inventory in 1995, the tree species composition has changed and birch is now dominant. The number of Scots pine/ha has decreased on all soil treatments but there are still high stem densities. There seems to be no evident advantage in planting of Scots pine since it has regenerated naturally to high numbers on all soil treatments. Natural regeneration of Norway spruce is unsatisfactory, but the species has shown satisfactory survival rates when planted. Comparing the other planted tree species, lodgepole pine has performed best in terms of tree survival and annual increment.

The highest number of stems has been found on ASKA. Here, in comparison to the other fertilized treatments, volume and biomass production was the lowest. P40K80 has higher productivity, but lower stem density than ASKA. The most productive soil treatment was P80K120. The MINERAL plot showed adequate productivity and especially downy birch showed high volume development and biomass production on this soil treatment.

It can be concluded that planting is not essential for the establishment of productive forests on terminated peat cutting areas, provided natural seed sources are present. Fertilization, on the other hand, is indispensable as fertilization initiates colonization. Colonization on the unfertilized treatments has still not improved even after 13 vegetation periods. Moreover, fertilization is needed to accelerate the establishment of dense stands (Tillman-Sutela *et al.* 2004). Näsi *et al.* (2004) found similar results in other studies.

It is possible that the roots of the trees on the fertilized treatments on Näsmyran have penetrated into the mineral soil since the residual peat layer is not deeper, most likely even shallower on average, than 1 m. However, it is undoubtedly that establishment and development of the trees on Näsmyran are the result of fertilization.

9. References

*Almquist, K., 2003. Svensk Flora, Liber AB, Stockholm, Sweden

Aro, L., 2000. Afforestation of cutaway peatlands in Finland. pp. 43-45 in Åman, P. (ed), 2000, Re-use of peat production areas. EU's Northern Periphery Programme project: Re-use of peatland areas. Proceedings from the 1st International Seminar, 2000, Oulu, Finland.

Aro, L. and Kaunisto, S. 2003. Jatkolannoituksen ja kasvatustiheyden vaikutus muorten mäntymetsiköiden ravinnetilaan sekä puuston ja juuriston kehitykseen paksuturpeisella suonpohjall (Effect of re-fertilization and growing density on the nutrition, growth and root development of young Scots pine stands in a peat cutaway area with deep peat layers, In Finnish, English summary). Suo – mires and peat 54(2):49-67. Finnish Peatland Society, Vammala, Finland.

Aro, L. and Kaunisto, S.J.J., 1998. Forestry use of peat cutaway areas in Finland. pp. 185-186 in Sopo, R. (ed.), 1998. The Spirits of Peatlands – Proceedings of the International Peat Symposium, 1998, Jyväskylä, Finland. International Peat Society, Jyväskylä, Finland.

*Bergenståhl, B., Söderström, L., Ulfvendahl, P.J., Weber-Grönwall, D., Nordlund, A., 1990. Fältbiologernas mossflora – fälthandbok över Sveriges vanligaste mossor. Fältbiologernas. Katarina Tryck AB, Stockholm, Sweden

Bluman, A., 1997. Elementary statistics - a step by step approach, 3rd edition. WCB/McGraw-Hill, USA

Connell, J. and Slatyer, R., 1977. Mechanisms of succession in natural communities and their role in community stabiliy and organization. pp. 1119-1145 in the American Naturalist, Vol. 11, 1997, by the university of Chicago, USA.

Engelmark, O. and Hytteborn, H., 1999. Coniferous forests. pp. 55-74 in Rydin, H., Sneijs, P. and Diekmann, M., 1999. Swedish plant geography, Acta Phytogeographica Suecica 84. Uppsala, Sweden.

*Hallingbäck, H. and Holmasen, I., 2000. Mossor - en fälthandbok, Interpublishing, Stockholm, Sweden (im Feld angewandt)

*Hallingbäck, T. and Holmåsen, I., 1982. Mossor: en fälthandbok. Interpublishing AB, Stockholm, Sweden.

*Hägglund, B. and Lundmark, J.-E., 1994. Handleding in bonitering – med Skogshögskolans boniteringssystem, del 3, markvegetationstyper-skogsmarksflora. Skogsstyrelsen, Jönköping, Sweden.

Hytönen, J., 2003. Effects of wood, peat and coal ash fertilization on Scots pine foliar nutrient concentrations and growth on afforested former agricultural peat soils. Silva Fennica 37(2): 219.239

Hytönen, J. and Kaunisto, S., 1999. Effect of fertilization on the biomass production of coppiced mixed birch and willow stands on a cutaway peatland. Biomass and Energy 17(6):455-469. Elsevier Science Ltd., London, United Kingdom.

Håkansson, M., 1994. PS: praktisk skogshandbok. Sveriges skogsvårdsförbund.

Hånell, 2004. Areal för skogsgödsling med träaska och torvaska på organogener jordar in Sverige – Miljöriktig användning av askor. Värmeforsk Service AB, Stockholm, Sweden.

Larsson, L.-E., 2001. Peat in Sweden-Cutaway peatlands to be restored. In Uosukainen, H. (ed), Re-use of peat production areas, pp. 34-41. EU's Northern Periphery Programme project: Re-use of peatland areas. Proceedings from the 3rd international seminar, Aberdeen, Scotland, UK, 70 pp.

*Moberg, R. and Holmåsen, I., 1995. Lavar – en fälthandbok. Interpublishing AB, Stockholm, Sweden

*Mossberg and Stenberg, 2003. Den nya nordiska floran. (W & W) Wahlström & Widstrand, PTC Tangen, Norway

Nilsson, T., Lundin, L. and Olsson, M., 1994. Beskogning av avslutede torvtäkter – problem och lösningar. Skogsfakta Nr. 8, 1994. SLU, Umeå, Sweden.

Näsi, N, Kubin, E. and Piispanen, J, 2004. Effects of wood- and peat-ash fertilization on nutrient status of peat an dprimary succession of the ground vegetation on cutaway peatland. pp. 472-477 in Päivänen, J. (ed), 2004. Wise use of peatlands – Proceedings of the 12th International Peat Congress, 2004,Tampere, Finland. International Peat Society, Saarijärvi, Finland.

Paavilainen, E. and Päivänen, J. 1995. Peatland Forestry-Ecology and Principles. Ecological Studies 111. Springer Verlag, Berlin.

Pöllänen, M., Renou, F., Feehan, J. and Farrell, E.P., 2004. The ecology of Betula species growing on industrial cutaway peatlands in Ireland. p. 500 in Päivänen, J. (ed), 2004. Wise use of peatlands – Proceedings of the 12th International Peat Congress, 2004,Tampere, Finland. International Peat Society, Saarijärvi, Finland.

*Rose, F. 1981. The Wild Flower Key – British Isles - N. W. Europe. Warne & Co., England

Schnitzler, A. and Closset, D., 2003. Forest dynamics in unexploited birch (Betula pendula) stands in the Vosges (France): structure, architecture and light patterns. pp. 205-220 in Forest Ecology and Management No. 183 (2003). Kluwer Acadamic Publishers, the Netherlands.

Segebaden, G., 1992. Contortatall i Sverige – en lägesrapport. Skogsstyrelsens contorta-utredning.

Svensson, J., Hånell, B. and Magnusson, T., 1998. Naturlig beskogning av utbrutna torvmarker genom insådd från omgivande skog- Tree and shrub colonization of abandoned peat winning fields by seeding from adjacent forests. Rapport 78. Rapporter i skogsekologi och skoglig marklära, institution för skoglig marklära, Swedish University of Agricultural Sciences, Uppsala, Sweden. 45 pp.

Tillmann-Sutela, E, Pasanen, J and Karhu, J., 2004). Fertilization improves the establishement of birch seedlings on the cutover peatland. pp. 1281-1286 in Päivänen, J. (ed), 2004. Wise use of peatlands – Proceedings of the 12th International Peat Congress, 2004,Tampere, Finland. International Peat Society, Saarijärvi, Finland.

Vasander, H. and Roderfeld, H., 1996. Restoration of peatlands after harvesting. pp. 143-147 in Vasander H. (ed) 1996. Peatlands in Finland. Finnish Peatland Society, Helsinki, Finland.

Wardle, D.A., Bardgett, R.D., Klironomos, J.N., Setälä, H., Van der Putten, W.H. and Wall, D.H. 2004. Ecological linkages between aboveground and belowground biota. Science 304, 1629-1633.

Westermann, C.J., 1981. Fertiliy of surface peat in relation to the site type and potential stand growth. Acta Forestalia Fennica, Vol 172, 1981. Suomen Metsätietieellinen Seura, Helsinki, Finland

References marked with * were used during the identification of plants. Further expertise on the identification was obtained from:

Greger Hörnberg, Department of Forest Vegetation ecology, SLU;
John Jeglum, Department of Forest Ecology, SLU;
and Kristoffer Hylander, Department of Landscape Ecology, Umeå University

10. Appendix

Table 2: Number of stems, volume and biomass per hectare and standard error of the mean for all tree species on P80K120

P80K120	**Total stems/ha**	**Stems <1,3m/ha**	**Stems >1,3m/ha**	**Volume m^3/ha**	**Biomass t/ha**
Natural regenation (n=10)					
Betula pubescens	**7 583**	**2 958**	**4 625**	**9,5**	**12,2**
s e mean	915	641	698	4,2	5,2
Betula pendula	**5 417**	**1 333**	**4 083**	**15,3**	**20,7**
s e mean	477	269	447	4,1	5,4
Betula spp.	**3 167**	**2 667**	**500**	**0,8**	**1,0**
s e mean	711	652	104	0,3	0,4
Salix spp.	**9 000**	**4 042**	**4 958**	**3,1**	**6,3**
s e mean	1 524	768	947	0,7	1,3
NR-Pinus sylvestris	**6 875**	**1 146**	**5 729**	**16,4**	**20,0**
s e mean	1 529	457	1 447	6,3	7,2
NR-Picea abies	**2 031**	**2 031**	**0**	**0,0**	**0,0**
s e mean	420	420	0	0,0	0,0
Sum (NR)	**34 073**	**14 177**	**19 896**	**45,0**	**60,2**
Planted (n=2)					
P+NR-Pinus sylvestris	**8 958**	**1 042**	**7 917**	**41,5**	**49,8**
s e mean	3 125	625	2 500	5,2	4,9
P+NR-Picea abies	**4 583**	**208**	**4 375**	**20,2**	**28,4**
s e mean	417	208	208	5,3	6,4
Larix laricina	**4 792**	**625**	**4 167**	**11,4**	**14,0**
s e mean	1 458	625	833	7,2	7,9
Picea mariana	**3 958**	**208**	**3 750**	**15,0**	**22,7**
s e mean	1 042	208	833	4,9	6,5
Pinus contorta	**3 750**	**0**	**3 750**	**57,1**	**62,2**
s e mean	417	0	417	3,0	2,0
Average (NR+P)+(P)	**5 208**	**417**	**4 792**	**29,0**	**35,4**
Total	**39 281**	**14 594**	**24 688**	**74,1**	**95,6**

Table 3: Number of stems, volume and biomass per hectare and standard error of the mean for all tree species on P40K80

P40K80	**Total stems/ha**	**Stems <1,3m/ha**	**Stems >1,3m/ha**	**Volume m^3/ha**	**Biomass t/ha**
Natural regenation (n=10)					
Betula pubescens	**11 375**	**6 333**	**5 042**	**6,6**	**8,6**
s e mean	1 426	1 382	830	1,9	2,3
Betula pendula	**6 958**	**2 500**	**4 458**	**8,6**	**11,4**
s e mean	697	493	615	2,5	3,2
Betula spp.	**2 458**	**1 625**	**833**	**0,7**	**1,0**
s e mean	685	587	311	0,3	0,4
Salix spp.	**7 958**	**6 792**	**1 167**	**0,3**	**0,8**
s e mean	1 461	1 357	377	0,2	0,4
NR-Pinus sylvestris	**7 865**	**2 865**	**5 000**	**12,1**	**15,7**
s e mean	1 381	711	1 085	3,0	3,8
NR-Picea abies	**1 510**	**1 510**	**0**	**0,0**	**0,0**
s e mean	438	438	0	0,0	0,0
Sum (NR)	**38 125**	**21 625**	**16 500**	**28,3**	**37,5**
Planted (n=2)					
P+NR-Pinus sylvestris	**13 333**	**3 125**	**10 208**	**37,5**	**48,4**
s e mean	2 500	1 875	4 375	8,0	9,3
P+NR-Picea abies	**4 375**	**1 042**	**3 333**	**12,7**	**19,0**
s e mean	625	208	417	0,9	1,9
Larix laricina	**1 875**	**0**	**1 875**	**8,2**	**10,1**
s e mean	208	0	208	0,2	0,2
Picea mariana	**3 958**	**417**	**3 542**	**14,0**	**21,2**
s e mean	625	417	208	3,2	3,7
Pinus contorta	**3 125**	**208**	**3 125**	**27,2**	**31,4**
s e mean	208	208	208	7,3	6,8
Average (NR+P)+(P)	**5 333**	**958**	**4 417**	**19,9**	**26,0**
Total	**43 458**	**22 583**	**20 917**	**48,2**	**63,5**

Table 4: Number of stems, volume and biomass per hectare and standard error of the mean for all tree species on ASKA

ASKA	Total stems/ha	Stems <1,3m/ha	Stems >1,3m/ha	Volume m^3/ha	Biomass t/ha
Natural regenation (n=10)					
Betula pubescens	**20 917**	**15 708**	**5 208**	**3,7**	**5,1**
s e mean	1 832	1 712	1 017	0,9	1,2
Betula pendula	**7 875**	**4 708**	**3 167**	**5,4**	**8,1**
s e mean	1 246	946	440	1,6	2,3
Betula spp.	**5 833**	**5 333**	**556**	**0,2**	**0,4**
s e mean	1 285	1 163	315	0,1	0,2
Salix spp.	**15 125**	**12 125**	**3 000**	**0,3**	**1,4**
s e mean	2 130	1 919	807	0,1	0,4
NR-Pinus sylvestris	**13 073**	**5 313**	**7 760**	**14,1**	**19,4**
s e mean	1 085	844	1 002	2,8	3,6
NR-Picea abies	**1 042**	**1 042**	**0**	**0,0**	**0,0**
s e mean	424	424	0	0,0	0,0
Sum (NR)	**63 865**	**44 229**	**19 691**	**23,8**	**34,4**
Planted (n=2)					
P+NR-Pinus sylvestris	**12 917**	**2 708**	**10 208**	**26,6**	**35,6**
s e mean	5 000	1 042	3 958	13,9	18,8
P+NR-Picea abies	**5 000**	**1 458**	**3 542**	**6,8**	**12,3**
s e mean	417	208	625	3,2	4,7
Larix laricina	**4 583**	**625**	**3 958**	**3,8**	**5,7**
s e mean	833	208	625	1,3	1,7
Picea mariana	**3 958**	**625**	**3 333**	**8,3**	**13,9**
s e mean	1 042	208	833	3,4	3,8
Pinus contorta	**3 750**	**0**	**3 750**	**30,4**	**34,9**
s e mean	417	0	417	0,3	0,4
Average (NR+P)+(P)	**6 042**	**1 083**	**4 958**	**15,2**	**20,5**
Total	**69 906**	**45 313**	**24 649**	**39,0**	**54,9**

Table 5: Number of stems, volume and biomass per hectare and standard error of the mean for all tree species on P0K0

P0K0	**Total stems/ha**	**Stems <1,3m/ha**	**Stems >1,3m/ha**	**Volume m^3/ha**	**Biomass t/ha**
Natural regenation (n=10)					
Betula pubescens	**5 250**	**4 000**	**1 250**	**0,9**	**1,2**
s e mean	1 370	1 214	367	0,5	0,7
Betula pendula	**2 167**	**1 625**	**542**	**1,5**	**2,5**
s e mean	579	348	412	1,0	1,6
Betula spp.	**2 833**	**2 667**	**167**	**0,1**	**0,2**
s e mean	642	580	92	0,1	0,1
Salix spp.	**2 667**	**2 583**	**83**	**0,0**	**0,0**
s e mean	754	724	83	0,0	0,0
NR-Pinus sylvestris	**3 906**	**3 490**	**417**	**0,5**	**0,7**
s e mean	996	818	208	0,3	0,4
NR-Picea abies	**2 292**	**2 292**	**0**	**0,0**	**0,0**
s e mean	510	510	0	0,0	0,0
Sum (NR)	**19 115**	**16 656**	**2 458**	**2,9**	**4,6**
Planted (n=2)					
P+NR-Pinus sylvestris	**4 167**	**3 750**	**417**	**0,2**	**0,4**
s e mean	2 083	1 667	417	0,2	0,4
P+NR-Picea abies	**833**	**625**	**208**	**0,1**	**0,3**
s e mean	417	625	208	0,1	0,3
Larix laricina	**1 250**	**0**	**1 250**	**0,7**	**1,2**
s e mean	1 250	0	1 250	0,7	1,2
Picea mariana	**1 250**	**625**	**625**	**1,9**	**3,1**
s e mean	1 250	625	625	1,9	3,1
Pinus contorta	**2 917**	**1 458**	**1 458**	**4,1**	**6,3**
s e mean	2 083	1 042	1 042	4,1	6,0
Average (NR+P)+(P)	**2 083**	**1 292**	**792**	**1,4**	**2,2**
Total	**21 198**	**17 948**	**3 250**	**4,3**	**6,8**

Table 6: Number of stems, volume and biomass per hectare and standard error of the mean for all tree species on KONTROLL

KONTROLL	**Total stems/ha**	**Stems <1,3m/ha**	**Stems >1,3m/ha**	**Volume m^3/ha**	**Biomass t/ha**
Natural regenation (n=2)					
Betula pubescens	**4 167**	**2 708**	**1 458**	**1,1**	**1,5**
s e mean	1 250	208	1 458	1,1	1,5
Betula pendula	**1 875**	**1 042**	**833**	**0,5**	**0,8**
s e mean	1 875	1 042	833	0,5	0,8
Betula spp.	**2 292**	**4 167**	**208**	**1,8**	**2,6**
s e mean	1 875	2 083	208	1,8	2,6
Salix spp.	**5 417**	**5 208**	**208**	**0,0**	**0,0**
s e mean	2 917	3 125	208	0,0	0,0
Pinus sylvestris	**3 958**	**3 750**	**208**	**0,3**	**0,4**
s e mean	208	417	208	0,3	0,4
Picea abies	**1 042**	**1 042**	**0**	**0,0**	**0,0**
s e mean	208	208	0	0,0	0,0
Total	**18 750**	**17 917**	**2 917**	**3,6**	**5,3**

Table 7: Number of stems, volume and biomass per hectare and standard error of the mean for all tree species on MINERAL

MINERAL	**Total stems/ha**	**Stems <1,3m/ha**	**Stems >1,3m/ha**	**Volume m^3/ha**	**Biomass t/ha**
Natural regenation (n=2)					
Betula pubescens	**13 750**	**5 208**	**8 542**	**10,7**	**14,4**
s e mean	3 333	1 458	1 875	5,9	7,7
Betula pendula	**7 292**	**2 708**	**4 583**	**21,6**	**27,9**
s e mean	2 708	208	2 500	9,1	11,8
Betula spp.	**833**	**625**	**208**	**0,9**	**1,1**
s e mean	417	208	208	0,9	1,1
Salix spp.	**1 458**	**833**	**625**	**0,4**	**0,7**
s e mean	625	833	208	0,3	0,4
NR-Pinus sylvestris	**11 042**	**5 208**	**5 833**	**8,8**	**12,5**
s e mean	625	1 042	1 667	2,2	3,4
NR-Picea abies	**3 125**	**3 125**	**0**	**0,0**	**0,0**
s e mean	625	625	0	0,0	0,0
Total	**37 500**	**17 708**	**19 792**	**42,3**	**56,5**

1	*Pinus* seedling	33	*Luzula multiflora*
2	*Betula* seedling	34	*Luzula pallescens*
3	*Picea* seedling	35	*Eriophorum vaginatum*
4	*Salix* Seedling	36	*Carex globularis*
5	*Hieracium* spp.	37	*Vaccinum mytrillus*
6	*Cirsium palustre*	38	*Lycopodium annotium*
7	*Rumex acetosella*	39	*Drosera rotundifolia*
8	*Orthilia secunda*	40	*Calluna vulgaris*
9	*Pyrola media*	41	*Empeditrum nigrum*
10	*Poaceae* spp.	42	*Vaccinum oxycoccus*
11	*Gynnocarpium dryopteris*	43	*Andromeda polifolia*
12	*Maianthemum bifolium*	44	*Vaccinum uligunosum*
13	*Equisetum palustre*	45	*Ledum palustre*
14	*Poa* spp.	46	*Betula nana*
15	*Calamagrostis* spp.	47	*Vaccinum vitis-idea*
16	*Deschampsia caespetosa*	48	*Arctostaphylos uva-ursi*
17	*Molinia caerulea*	49	Mushroom/Svamp
18	*Carex chordorrhiza*	50	*Polytrichum (strictum)*
19	*Festuca* spp.	51	*Polytrichum commune*
20	*Carex aquatilis*	52	*Pleurozium shreberi*
21	*Carex brunnescens*	53	*Aulacomnium palustre*
22	*Carex canescens*	54	*Hylocomnium splendens*
23	*Carex dioica*	55	*Ptilium cristata*
24	*Carex magellanicum*	56	*Sphagnum centrale*
25	*Carex nigra*	57	*Sphagnum capillifolium*
26	*Carex* spp.	58	*Sphagnum russowii*
27	*Epilobium (angustifolium)*	59	*Mylia anomale*
28	*Festuca ovina*	60	*Cladonia* spp.
29	*Deschampsia flexuosa*	61	*Dircranella cerriculata*
30	*Trichosphorum alpinum*	62	*Callergion stramineum*
31	*Trichosphorum caespitosum*	63	*Pohlia nutans*
32	*Deschampsia* spp.	64	*Dicranum polysetum*

Table 8: List of species in the field and bottom layer

Calculations:

For the calculation of volume over bark Näslunds minor volume functions (Håkanssons, 1994) were used:
Pinus sylvestris
d > 5 cm: $v = 0{,}09314d^2 + 0{,}03069d^2h + 0{,}002818dh^2$ and
d < 5 cm: $v = 0{,}22 + 0{,}08786d^2 + 0{,}03045d^2h + 0{,}002809dh^2$
Picea abies, Picea mariana
d > 5 cm: $v = 0{,}1202d^2 + 0{,}01504d^2h + 0{,}02341dh^2 - 0{,}06590h^2$ and
d < 5 cm: $v = 0{,}22 + 0{,}1150d^2 + 0{,}01410d^2h + 0{,}01047dh^2$
Betula pendula, Betula pubescens, and Betula spp.
d > 5 cm: $v = 0{,}03715d^2 + 0{,}0{,}892d^2h + 0{,}004983dh^2$ and
d < 5 cm: $v = 0{,}11 + 0{,}09929d^2 + 0{,}006405d^2h + 0{,}01382dh^2$
Pinus contorta
$v = 0{,}1121d^2 + 0{,}02870d^2h – 0{,}000061d^2h^2 – 0{,}09176dh + 0{,}01249dh^2$
The following formulas for these tree species were used:
Eriksson (1973)
Salix spp.:
$v = 0{,}01548d^2 + 0{,}03255d^2h – 0{,}000047d^2h^2 – 0{,}01666dh + 0{,}004859dh^2$
Carbonnier (1954)
Larix laricina
$v = 0{,}04801d^2h + 0{,}08886d^2 – 0{,}01012d^3 – 0{,}08406dh + 0{,}1972h$

For the calculation of biomass over bark the biomass functions according to Marklund (1988) were used:
Pinus sylvestris, Larix laricina and *Pinus contorta*:
stem over bark: $-2{,}6768 + (0{,}196^2/2) + 7{,}5939d/(d+13) + 0{,}0151h + 0{,}8799*\ln*h$;
living branches (including needles): $-2{,}5413+(0{,}456^2/2)+13{,}3955d/(d+10)+ (-1{,}1955*\ln*h)$;
dead branches: $-5{,}8926+(0{,}945^2/2)+7{,}127d/(d+10)+(-0{,}0465h)+1{,}106*\ln*h$.
Betula pendula, *Betula pubescens*, *Betula* spp. and *Salix* spp.:
(stem over bark): $-3{,}5686 + 0{,}195^2/2 + 8{,}2827d/(d+7) + 0{,}0393h + 0{,}5772*\ln*h$;
living branches: $-3{,}3633+(0{,}531^2/2)+10{,}2806d/(d+10)$;
dead branches: $-6{,}6237+1{,}162^2/2+11{,}2872d/(d+30)+(-0{,}3081h)+2{,}6821*\ln*h$
Picea abies and *Picea mariana*:
(stem over bark): $-2{,}1702 + 0{,}172^2/2 + 7{,}469d/(d+14) + 0{,}0289h + 0{,}6828*\ln*h$;
living branches (including needles): $-1{,}2063+0{,}374^2/2+10{,}9708d/(d+13)+(-0{,}0124h)+(-1{,}2063*\ln*h)$;
dead branches: $-4{,}6351+1{,}065^2/2+3{,}6518d/(d+18)+(-0{,}0493h)+1{,}0129*\ln*h$

Correction factor Sf^2/2 (log bias) included in biomass function.